Fermi National Accelerator Laboratory

Measurement of the W Mass at CDF

L. Nodulman

For the CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

HEP Division, Argonne National Laboratory
Argonne, Illinois

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HEP Division, Argonne National Laboratory, Argonne, Illinois 60439, USA

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The CDF collaboration has used electron and muon decays of the W boson in a sample of $\sim 19pb^{-1}$ to measure $m(W) = 80.41 \pm 0.18$ GeV/c^2. The measurement is discussed in terms of the prospects for the improved accuracy of future measurements.

1 Introduction

The initial estimates of the W boson mass were derived from the study of neutrino interactions. These mesurements now collectively give[1] $M(W) = 80.24 \pm 0.24$ GeV/c^2. One can combine precise e^+e^- measurements at the Z to infer an W mass by assuming electroweak theory. Although some of the experimental measurements are in apparent conflict, the combination gives[2] $m(W) = 80.36 \pm 0.06$ GeV/c^2. The CDF collaboration has recently directly measured the W boson mass[3] $m(W) = 80.41 \pm 0.18$ GeV/c^2 using $\sim 19pb^{-1}$ from "run 1a" (1992/93). This sample gives 5718 $W \rightarrow e\nu$ events and 3268 $W \rightarrow \mu\nu$ events. This precision scales statistically with luminosity from the earlier measurement,[4] which used a separate $\sim 4pb^{-1}$ sample giving $m(W) = 79.91 \pm 0.39$ GeV/c^2.

We have recorded a new "run 1b" sample of $\sim 90pb^{-1}$ and perhaps $\sim 25pb^{-1}$ more will be obtained by next summer. Major upgrades to the accelerator and both the CDF and D0 detectors will follow, and "run 2" should provide samples of more than $2fb^{-1}$ for measurements from each detector by perhaps 2002. The components of the ± 0.18 GeV/c^2 uncertainty are shown in Table 1, and these components will be discussed in terms of scaling to the larger samples.

2 Detector scales and resolutions

2.1 Muon measurement

We use the $J/\psi \rightarrow \mu\mu$ mass to determine the momentum scale. Although many effects contribute to the momentum scale uncertainty, two dominate: the dE/dx correction for the ψ muons (p_T typically 3 GeV/c), and the extrapolation to W leptons (p_T typically 38 GeV/c). The uncertainty on dE/dx comes from the uncertainty in the inner detector material and its composition. The material is determined from the tail of the E/p distribution from the electrons in the W candidates. We conservatively allow different assumptions about its composition. We have since developed confidence in using a

Table 1: Components of the uncertainty in the CDF W mass measurement from run 1a, in MeV/c^2.

Source	$W \rightarrow e\nu$	$W \rightarrow \mu\nu$	Common
Statistics	145	205	-
Lepton Scale	120	50	50
Momentum	50	50	50
E/p (energy)	110	-	-
Other	130	120	90
Lepton Res.	80	60	-
Recoil model	60	60	60
e/μ towers/ID	25	10	5
Trigger	0	25	-
Background	10	25	-
$W p_T$	45	45	25
PDF	50	50	50
QED	20	20	20
QCD	20	20	20
Fitting	10	10	-
Overall (180)	230	240	100

more precise material determination using conversions, see Fig. 1. This improved determination should scale statistically with luminosity as long as we maintain the low energy inclusive electron trigger used to provide the conversion sample. The ψ peak, 60000 events in run 1a, is be studied as a function of many variables, notably p_T. The high statistics allows good control of tracking systematics. The inclusive electron and ψ triggers are used for our b physics program as well as for calibration. Both of these triggers have been continued for 1b and will be retained for run 2.

Measurement resolutions need to be well known in order to determine the W mass precisely; assuming an overall resolution which is too high gives a low mass value. The muon resolution is determined by fitting the width of the $Z \rightarrow \mu\mu$ peak. This clearly improves with luminosity. The measurement resolution for 1b is slightly

worse due to higher occupancy and ageing in the tracking chamber. This is not the leading resolution overall, so the statistical error on the W mass using muons will not be hurt much. For run 2 there will be a replacement tracker which is still under study.
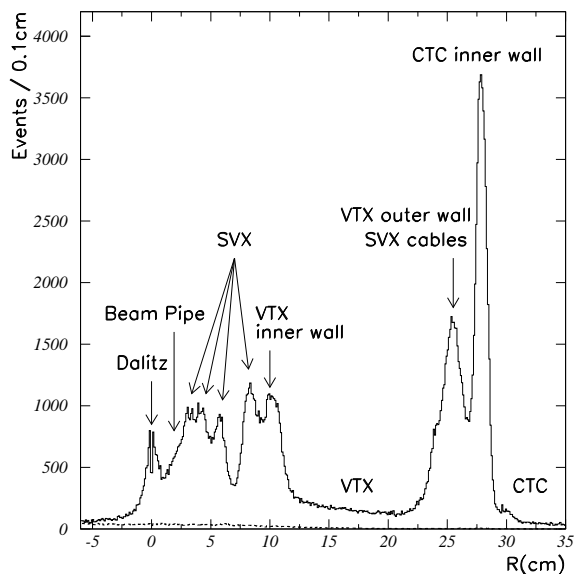

Figure 1: The material upstream of the momentum tracker (CTC) as seen in the rate of photon conversions. SVX is the silicon vertex detector and VTX is the vertex drift chambers. The lower curve is background to the conversions.

2.2 Electron measurement

The inclusive electron sample is used to equalize gains in the central electromagnetic calorimeter. The E/p peak from the W electrons is fit to a radiative Monte Carlo to set the overall scale. The material is determined from the tail of the E/p distribution. As discussed above, this material determination should improve nicely. The large ($\sim$ 140000) inclusive electron sample is quite valuable in controlling electromagnetic calorimeter systematics. Very pure W and conversion samples allow a good understanding of the influence of the fakes in the inclusive sample.

The electron resolution is determined by fitting the width of the $Z \to ee$ peak. The width of the peak of the E/p distribution is well measured and is used as a check. It could be used to anticorrelate the electron and muon resolution, reducing the uncertainty in the combined result.

The EM calorimeter is gradually losing light yield. The loss is not large enough to be significant. The additional material which will inevitably be part of the run 2 tracking will lower electron efficiency and widen the E/p peak. A likely scenario is that where we now have 8% X0, with 5 silicon layers and a fiber tracker, we will have

12%. Note that with an extremely large sample as is expected for run 2, the uncertainty penalty paid if the Z mass is used to set the scale may not be important.

2.3 Neutrino measurement

In this measurement as in previous ones[4,5] we fit a transverse mass distribution using Monte Carlo templates. Some combination of innovation and computer improvement should be able to keep the Monte Carlo statistics of increasingly sophisticated models up so that the fitting itself is not an important source of uncertainty. One must be able to reproduce the neutrino p_T, which is the 2D sum of the reflection of the lepton p_T and the net recoil energy measured by the overall calorimeter $|\eta| < 3.6$ with calorimeter towers effected by the lepton removed. Implicit isolation effects of the lepton identification (ID) and uncertainty in the average E_T to put back for whichever towers seems appropriate to remove give a bias uncertainty in the recoil response. The uncertainty is essentially statistical.
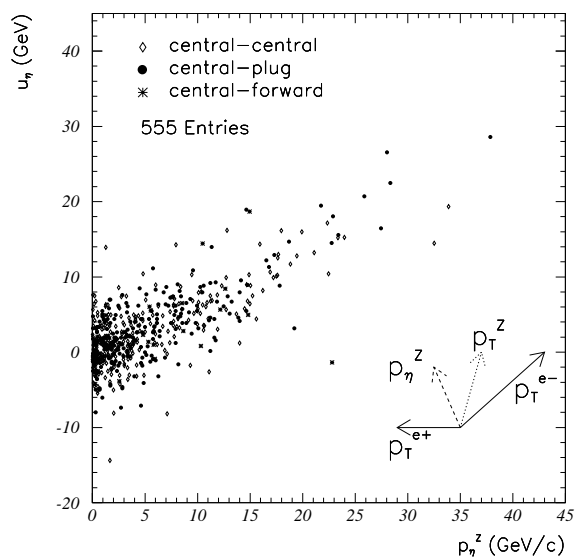

Figure 2: The projection on the η direction, as illustrated, the bisector of the two electron directions, of the $Z p_T$ as measured by the electrons versus the recoil projection using the calorimeter "u" for the Z candidates used as a lookup table. One electron is always in the central calorimeter.

Other W mass measurements have modelled the underlying event and recoil measurement, "u," with parameterizations which are constrained by minimum bias event response and the measured recoil response of Zs where both leptons are measured with understood systematics. For the current CDF analysis, the electron Z sample with at least one central leg was used directly in the Monte Carlo as a lookup table; one picks an appropriate event with the $W p_T$ desired by taking a Z event with

Zp_T appropriate as measured by the electrons and using the underlying event with the two electrons removed. This procedure has an uncertainty that scales directly with the number of Z events and uncertainties associated with unfolding the electron resolution and Zp_T at low Zp_T, which are statistically constrained.

The underlying event acts as noise in measuring the neutrino and thus transverse mass. The underlying event and recoil measurement is illustrated in Fig. 2. To avoid increasing overall resolution due to underlying event, the calorimeter response is not scaled up to give the best estimate of recoil and thus transverse mass. This creates sensitivity to Wp_T. Extra minimum bias events overlapping W events at high luminosity contribute to this resolution in a straightforward way. They should increase the statistical uncertainty for 1b by $\sim 15\%$. For run 2 the number of bunches increases from 6 to 36 or ~ 100, and considerably increased luminosity can be made before the 1b level of extra events is reached.
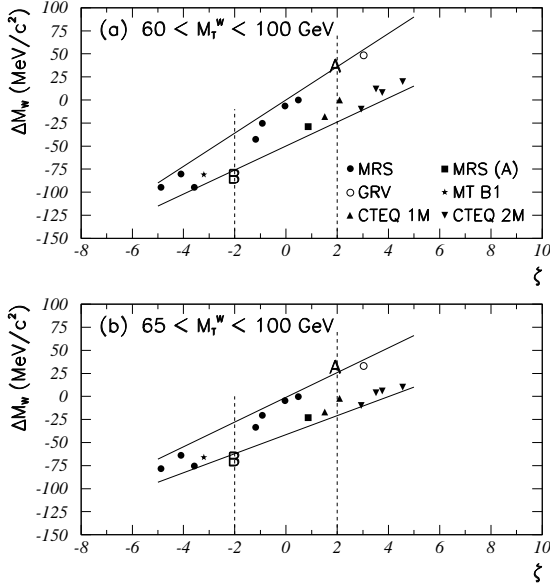

Figure 3: The change in W mass versus the signed standard deviation of agreement with the measured W charge asymmetry for different PDFs. Note the difference in slope and width of the band with lower bound on the fitting region, a) 60 and b) the nominal 65 GeV/c².

3   Miscellaneous detector issues

For electron events, there are many overlapping paths through the trigger, and it is easy to show that energy dependent efficiency is insignificant. Muons always require the track trigger, and the associated uncertainty comes from the statistics of the samples used to demonstrate the lack of p_T dependence.

The contribution of $W \rightarrow \tau\nu$, $\tau \rightarrow e$ or μ can be readily built into the Monte Carlo generation. A bigger

effect for muons is $Z \rightarrow \mu\mu$ with one muon lost. The calculation of this background scales with Z statistics. The loss will be reduced in run 2 as the forward muon toroids will be placed more favorably. Other backgrounds are smaller and the uncertainties are statistical.
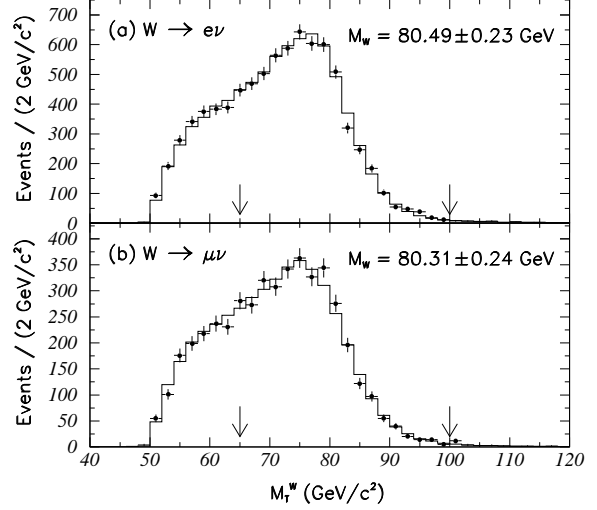

Figure 4: The transverse mass fit for the 1a CDF W mass measurement for a) electrons and b) muons.

4   Production model issues

The production Monte Carlo uses a leading order matrix element and NLO PDFs (MRSD'_ nominal). A Wp_T distribution is put in. We start with the shape of the observed Zp_T distribution with equivalent selection, and scale that shape to get agreement with the measured rms of the component of recoil perpendicular to the lepton direction. This is decoupled from lepton systematics. The recoil spectrum itself is used as a check. The uncertainties associated come from the statistical power of the constraint as well as constraints on more complicated distortions of the Wp_T shape which are also statistical. Some analyses use theoretical prediction ranges but with improved statistics, consistency with the data will become an even stronger constraint; the same analysis should be able to measure the Wp_T distribution at low Wp_T.

Uncertainty in proton structure is less easy to extrapolate. The current uncertainty is derived by taking the band made by the available PDFs in ΔMW versus net W charge asymmetry, see Fig. 3, and constraining it to within two standard deviations of agreement with our measured asymmetry.[6] We use the extreme range of the area allowed to define one standard deviation. Note that the width of the band implies that even a perfect asymmetry measurement would not help beyond $\sim \pm 25$
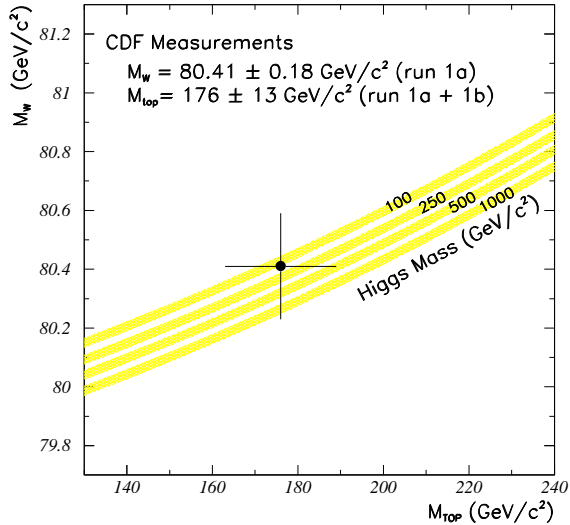
Figure 5: The CDF measurements of the W and top masses applied to the range of possible Higgs masses.

Figure 6: Preliminary transverse mass distributions for 1b CDF data.

MeV/c^2. This is not yet a concern for 1b, and for run 2 perhaps once could directly measure W production completely as a function of rapidity, or perhaps one could trade statistical uncertainty by raising the lower bound of the transverse mass fit region.

The uncertainties taken for higher order effects for QED and QCD reflect the level of our investigation. Additional work in these areas will be needed.

5 Conclusions

The fits giving the W mass measurement are shown in Fig. 4. Combining this measurement of $m(W) = 80.41 \pm 0.18$ with the previous CDF measurement[4] and UA2[5] and taking 85 MeV/c^2 as common in calculating the uncertainty gives $m(W) = 80.33 \pm 0.16\,GeV/c^2$. A final update of the D0 1a measurement is expected soon.[7] The measurement of the W mass, along with the top mass, is beginning to approach the accuracy of Higgs constraint[8] from precision measurements using e^+e^- colliders at the Z as seen in Fig. 5. Eventually the top and W mass measurements should dominate. We hope to get to $\sim \pm 90\,MeV/c^2$ for the W using CDF data from the current run. The transverse mass distributions for 80 pb^{-1} of 1b, not yet well calibrated, are shown in Fig. 6. The run 2 measurement is a more difficult projection, but with 100 times the 1a luminosity it should compete well the $\sim \pm 40\,MeV/c^2$ projected for all detectors combined for LEP200.[9] Clearly the level of effort needed for the analysis will grow considerably. The run 2 upgraded D0 detector should provide comparable results although the common systemat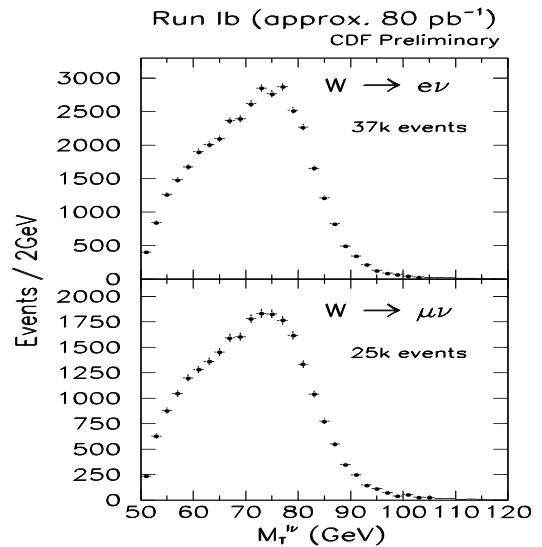ic uncertainties may be proportionally larger. We may be able to guide the Higgs search at LHC if this is not preempted by LEP200.

References

1. D. Harris, these proceedings.
2. J. Busenitz, these proceedings.
3. F. Abe *et al.* (CDF), *Phys. Rev. Lett.* **75** (1995) 11. F. Abe *et al.* (CDF), Phys. Rev. to be published, preprint FERMILAB-PUB-95/033-E.
4. F. Abe *et al.* (CDF), *Phys. Rev. Lett.* **65** (1990) 2243. F. Abe *et al.* (CDF), *Phys. Rev.* **D 43** (1991) 2070.
5. J. Alitti *et al.* (UA2), *Phys. Lett.* **B240** (1990) 150.
6. F. Abe *et al.* (CDF), *Phys. Rev. Lett.* **68** (1992) 1458.
7. M. Rijssenbeek (D0), private communication.
8. The bands are calculated with a program based on F. Halzen and B. A. Kniehl, *Nucl. Phys.* **B353** (1990) 567.
9. P. Perez, these proceedings.